

# (12) UK Patent Application (19) GB (11) 2 149 551 A

(43) Application published 12 Jun 1985

(21) Application No 8427940

(22) Date of filing 5 Nov 1984

(30) Priority data

(31) 8329667  
8421595

(32) 7 Nov 1983  
24 Aug 1984

(33) GB

(51) INT CL<sup>4</sup>  
G08B 19/00

(52) Domestic classification  
G4N 5A 7X EG

(56) Documents cited  
GB A 2130776  
GB A 2122399  
GB A 2089081  
GB 1498372  
GB 1020481

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(58) Field of search  
G4N

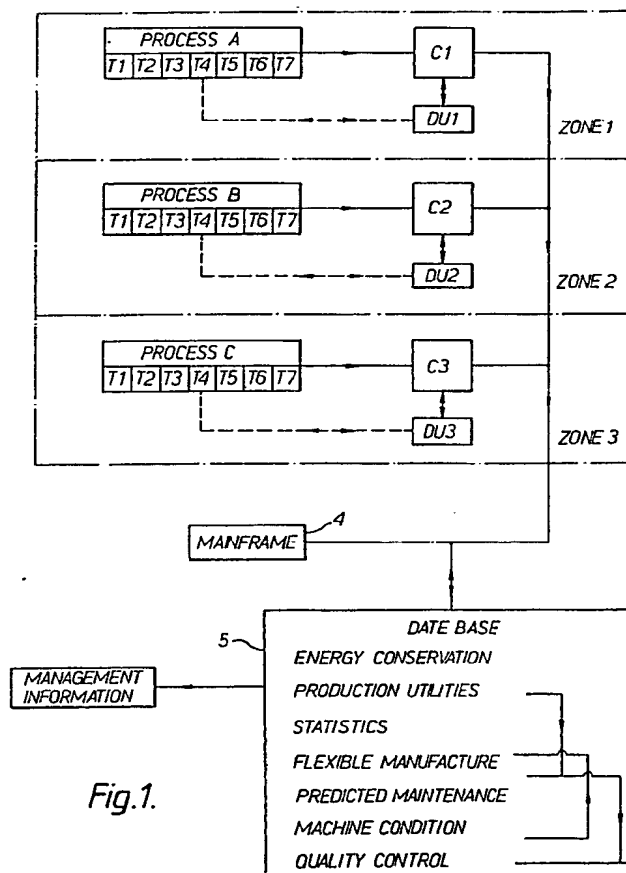
## (54) Apparatus for monitoring the operation of a system

(57) In a plant in which different (but related) processes (A, B, C, etc., Figure 1) are performed in respective zones (1, 2, 3, etc.) and wherein (in each zone) operational characteristics of the various steps of each process are sensed by local transducers (T<sub>1</sub>, T<sub>2</sub>, T<sub>3</sub>, etc.), a monitoring system comprises:-

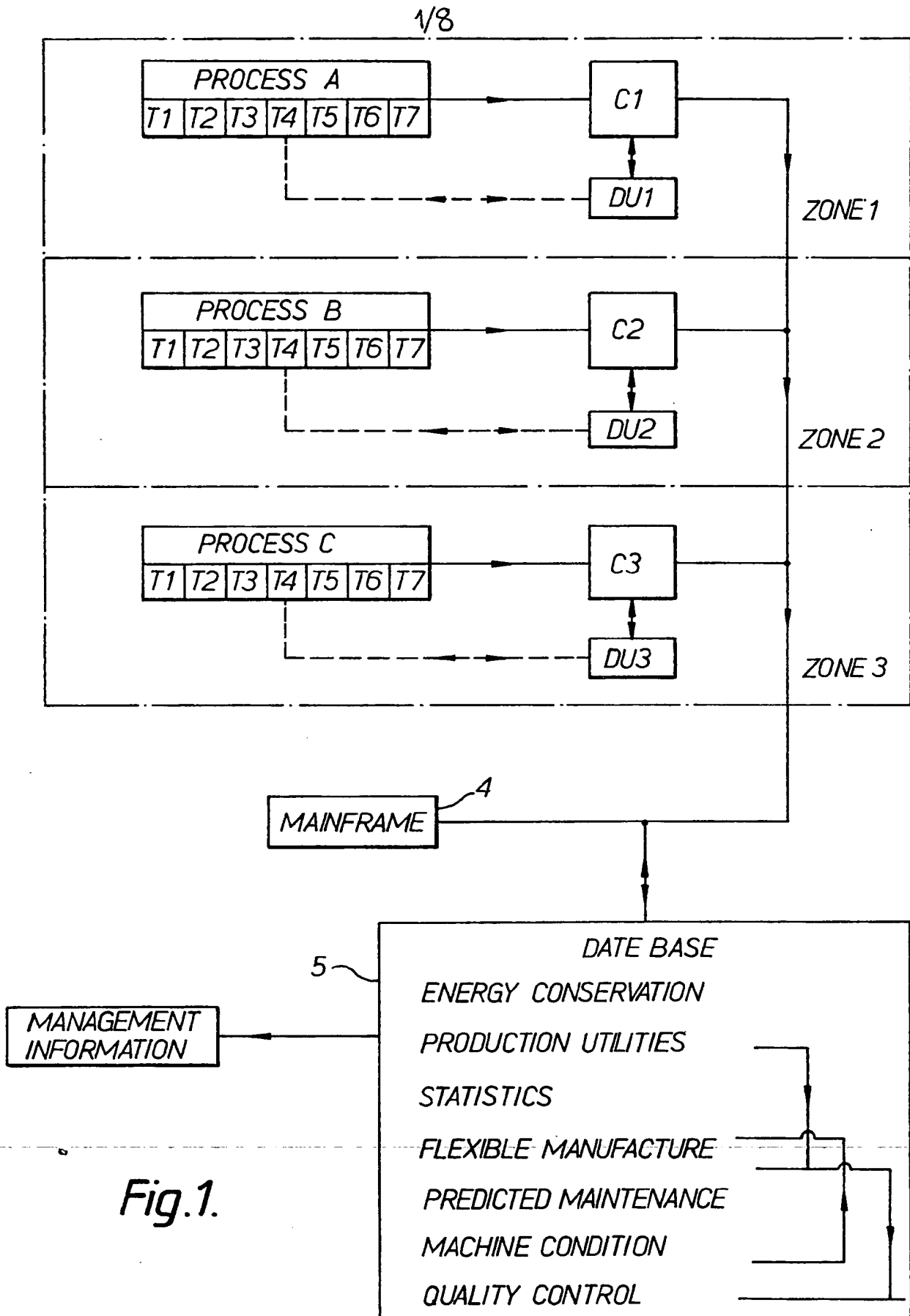
(a) In each zone a local processor (C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub> etc.) which receives the outputs of the local transducers and which is capable of generating a local (zone) warning in the event of a malfunction within the zone.

(b) a central computer 4 which receives the outputs of the local processors (C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>, etc.) and which is effective to evaluate and optimise the operation of the plant as a whole.

In the event of a local malfunction being indicated, a mobile diagnostic unit (DU<sub>1</sub>, DU<sub>2</sub>, DU<sub>3</sub>, etc.) is provided, wherewith a zone supervisor may interrogate the source of malfunction.



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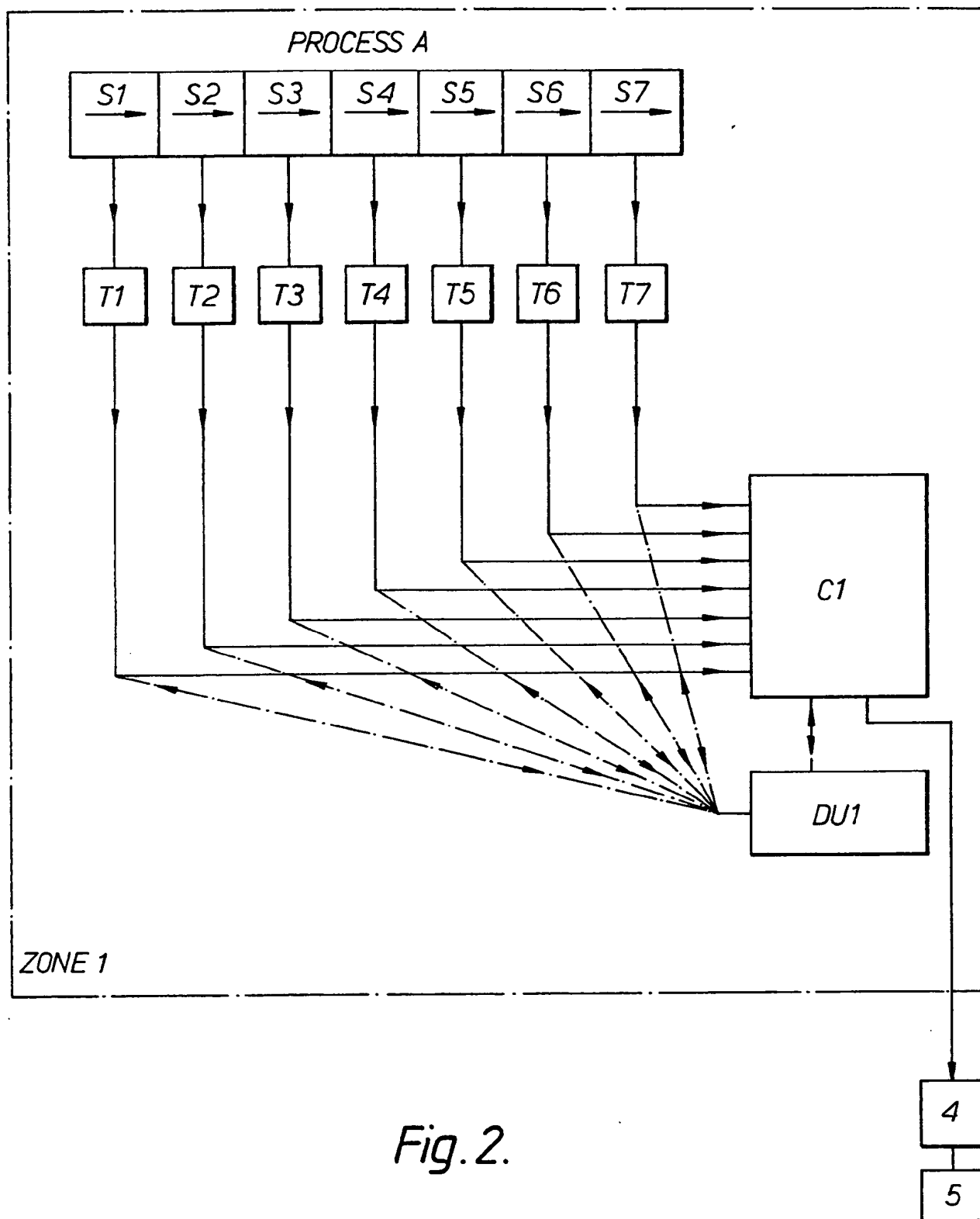
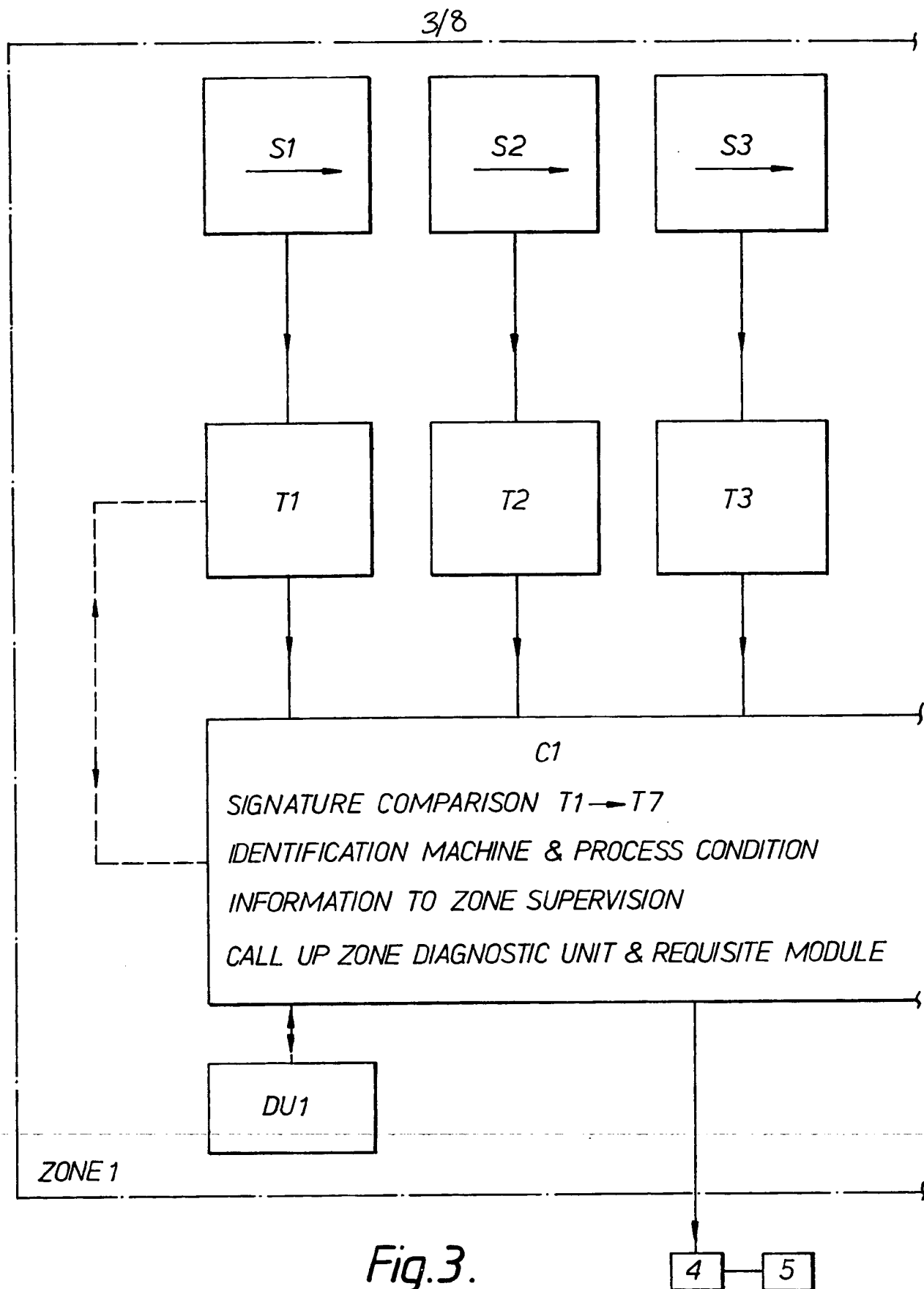
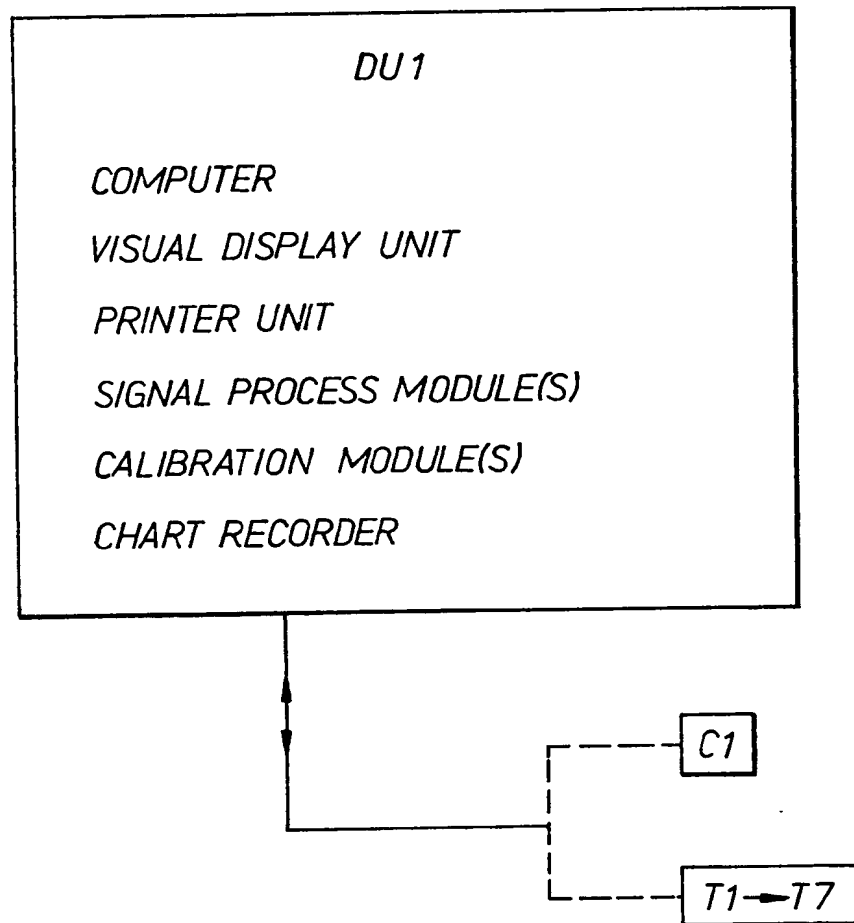


Fig. 2.



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ZONE 1*Fig. 4.*

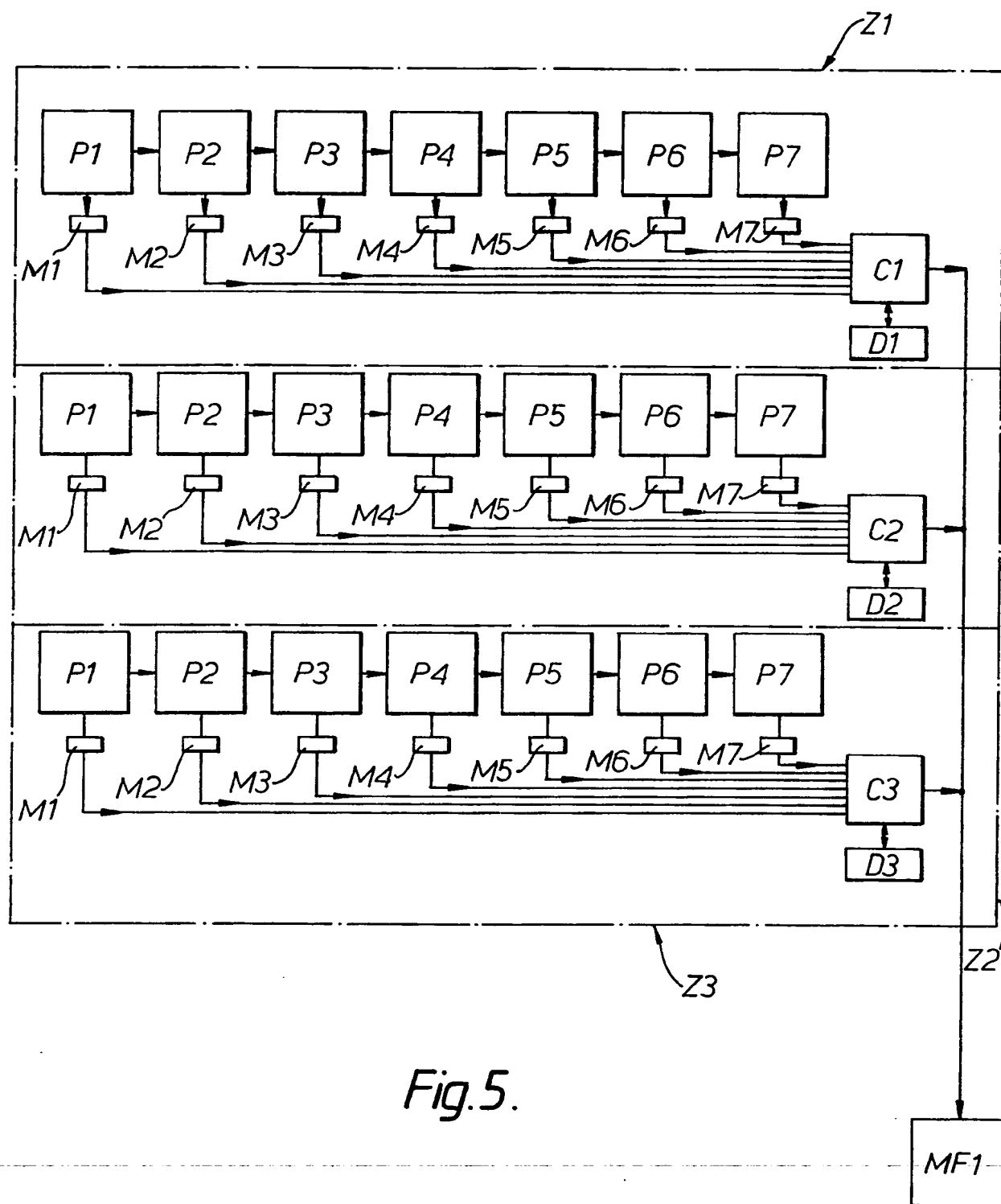
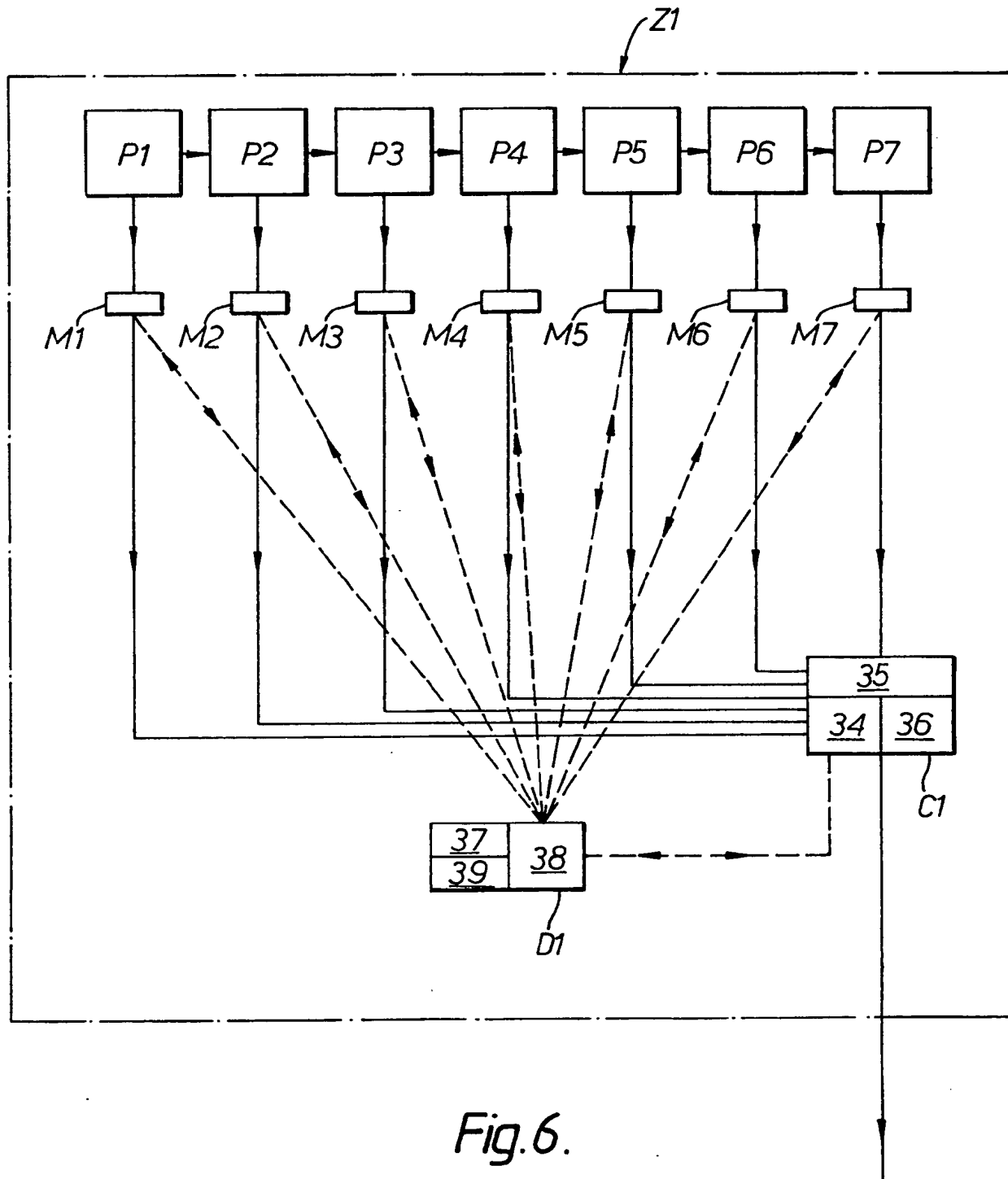


Fig. 5.



*Fig. 6.*

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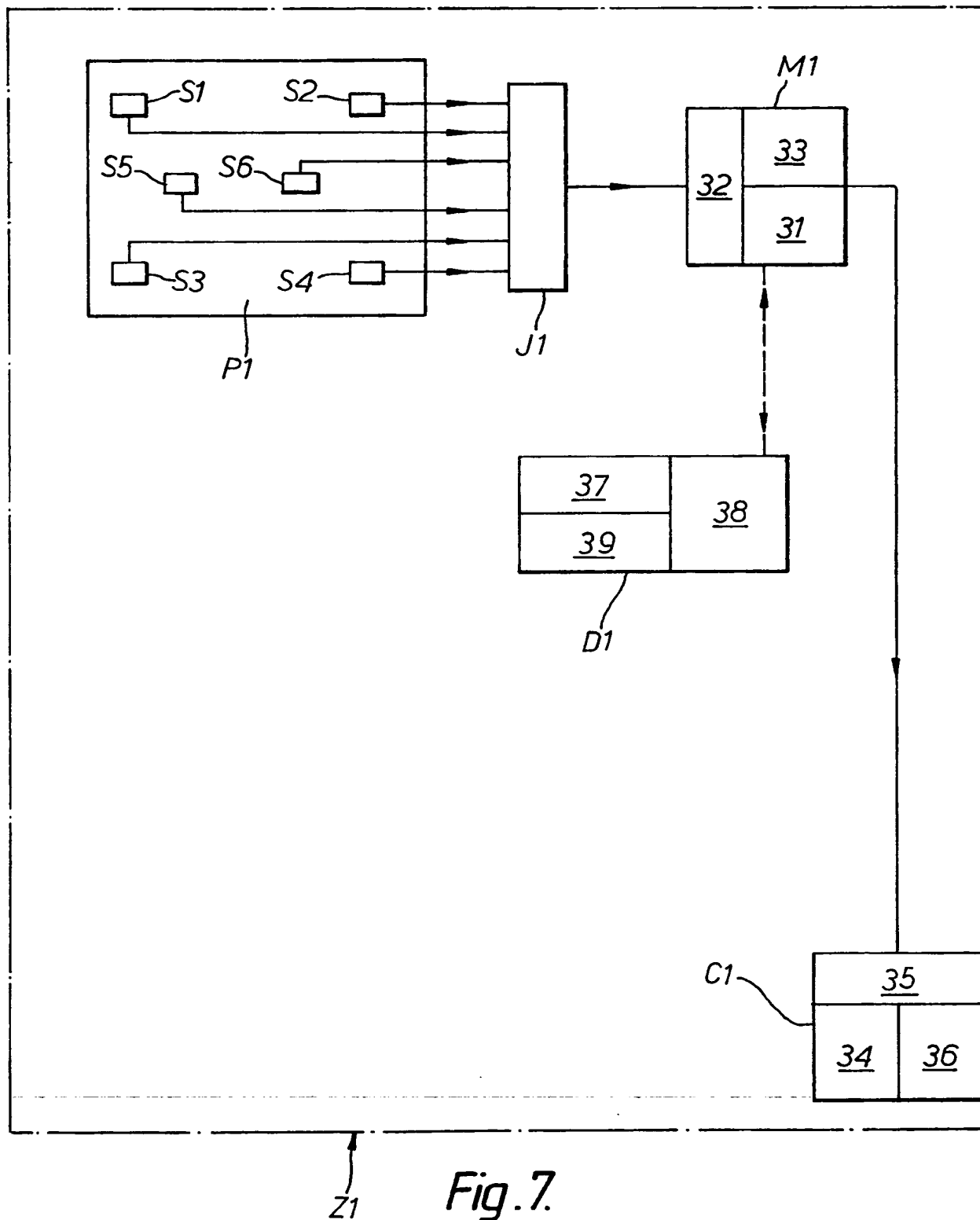


Fig. 7.

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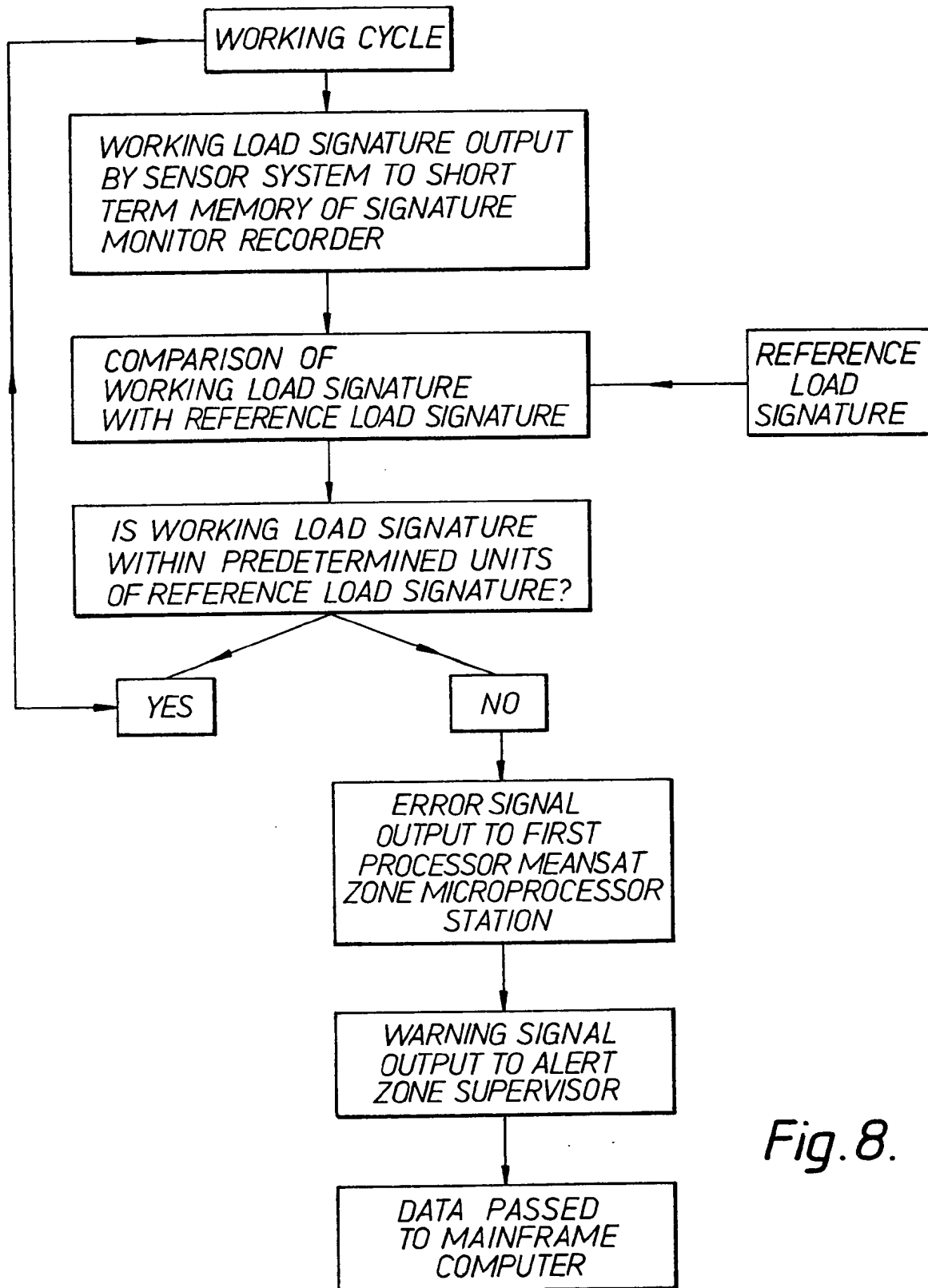


Fig. 8.

## SPECIFICATION

**Apparatus for monitoring the operation of a system**

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This invention relates to apparatus for monitoring the operation of a system.

With increasing use of automated production lines and systems, the demand for apparatus to monitor the operation of such systems has grown. Thus, sensors such as transducers have been used to measure a variety of the operational characteristics or signatures, for example, mechanical, physical or chemical variables or parameters, of a machine or plant.

Recently, signature recorders have been developed to record and display the outputs of such sensors.

However, there is still a need for monitoring apparatus which requires the minimum of supervision and moreover enables the operation of and any faults in a production line to be monitored so that the down time of the production line can be minimised, thereby increasing efficiency.

For example, when setting a press following a die-change or maintenance, it is imperative that the two die halves mate and exert the correct pressure on the blank material from which the pressing is formed. On double-action mechanical presses, to ascertain that the blank material clearance is obtained, it is known to employ matchsticks and plasticine, the practice being to insert plasticine on the lower die-half and, after completing a press cycle, measure the thickness of the plasticine which represents the die and effective draw clearance. The matchsticks are inserted at each corner of the blankholder and their crushed thickness compared to ensure that the blankholder has all-round even clearance.

For concluding a successful die-change much depends upon the experience and craft skills of the die-setter.

To obtain the correct settings, the setter may have to make five to ten test pressings before good pressings are achieved. This setting operation may take an hour or more and if a die-change is carried out by people with insufficient experience with a particular press, the lack in symbiosis can generate much longer downtime and more scrap pressings.

The press shop of a large manufacturing plant may comprise, for example, twenty press lines with each line consisting of seven linked presses. The critical function of three-dimensional forming is carried out by a first (lead) press in each line and it is this press, and its die-setting, that is most important because until a lead press die change is concluded the whole press line is at a standstill. Die-changeover may take place at least once in every forty eight hours on each press line which incurs a considerable downtime cost.

The nature of mechanical presses is such that once a satisfactory number of panels following a die change have been produced, subsequent pressings have to be continuously examined for

flaws. For example material blanks are lubricated prior to loading into the press and if the lubricant does not reach the right place during a press cycle a damaged pressing may emerge. Again, minute differences in material properties, e.g. thickness or ductility, may necessitate adjustments to the blankholder load and subsequent matchstick gauging. Hence downtimes do not end with the die-changeovers.

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It is known to provide a press with a counting system which provides the press shop management with information as to whether or not a press operation has produced a pressing by sensing the peak load of each press cycle. This system comprises sensors, typically strain gauges, mounted on the press pillars and equipment for obtaining from the strain gauges an output signal representative of the peak load applied during a press cycle. In the course of operating such a pressing system it has been observed by visual display means, that a specific die pressing combination produces its own characteristic signature.

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The present invention aims to use an operational characteristic produced by a piece of apparatus or a machine to monitor the operation of a system and provide information on trends in wear and other malfunctions which can be used by shop management and/or factory management to deduce critical paths in preventative maintenance, downtime costs, and availability of alternative sources of manufacture.

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According to one aspect of the present invention, there is provided apparatus for monitoring the operation of a system having a plurality of operational zones, each zone having a plurality of operational characteristics, the apparatus comprising: a respective sensor means for detecting each operational characteristic; a plurality of first processor means each associated with a respective operational zone for receiving signals representing the operational characteristics of the zone, for identifying when an operational characteristic of the zone varies from a predetermined desired characteristic and for delivering an error signal when a variation is detected to alert a zone supervisor; and a second processor means for receiving data from the plurality of first processor means to control overall operation of the system.

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Preferably, each operational characteristic is produced by a respective operational location in a zone and a plurality of diagnostic units are provided for determining the reason for a variation in an operational characteristic, each diagnostic unit being associated with a respective zone and first processor means and being movable between operational locations in the zone so that, when a first processor means delivers an error signal, a zone supervisor may move the associated diagnostic unit to the operational location at which the operational characteristic variation is occurring to determine the reason for the variation.

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In a second aspect, the present invention provides apparatus for monitoring the operation of a system having a plurality of operational zones, each zone having a plurality of operational loca-

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tions each having an operational characteristic, the apparatus comprising: a respective sensor means for detecting each operational characteristic; a plurality of first processor means, each associated with a respective operational zone for receiving signals representing the operational characteristics of the zone, for identifying when an operational characteristic of the zone varies from a predetermined desired characteristic and for delivering an error signal when a variation is detected to alert a zone supervisor; and a plurality of diagnostic units for determining the reason for a variation in the operational characteristic of an operational location, each diagnostic unit being associated with a respective zone and first processor means and being movable between operational locations in the zone so that when a first processor means delivers an error signal a zone supervisor may move the associated diagnostic unit to the operational location at which the operational characteristic variation is occurring to determine the reason for the variation.

The present invention also provides a system having a plurality of operational zones, each zone having a plurality of operational characteristics, and incorporating apparatus in accordance with the first or second aspect of the invention.

Comparison between the sensed operational characteristics and the desired predetermined characteristics may be carried out by the first processor means or separate comparison means may be provided. In such a case, the comparison means will usually comprise a respective comparator associated with each sensor. Preferably each comparison means comprises a signature monitor recorder including a microprocessor, a short term memory and a long term memory.

In a preferred arrangement, each diagnostics unit comprises a trolley mounted interface unit, micro-computer and visual display unit.

For a better understanding of the present invention, and to show how the same may be put into effect, reference will now be made, by way of example, to the accompanying drawings, in which:

*Figure 1* is a schematic diagram of a system incorporating apparatus in accordance with one embodiment of the invention for monitoring the operation of a system comprising an arrangement for manufacturing gear boxes;

*Figure 2* is a schematic block diagram illustrating a zone of the system shown in *Figure 1* and the part of the apparatus incorporated therein;

*Figure 3* is an enlarged block diagram of part of the zone of *Figure 2*;

*Figure 4* illustrates schematically the basic components of a diagnostics trolley of the apparatus;

*Figure 5* is a schematic block diagram of apparatus in accordance with another embodiment of the invention for monitoring the operation of a system comprising three lines of presses;

*Figure 6* is a schematic block diagram of that part of the apparatus of *Figure 5* which is associated with a single line of presses;

*Figure 7* is a schematic block diagram illustrating in further detail that part of apparatus which is as-

sociated with a single press; and

*Figure 8* is a flow chart illustrating the sequence of events following output of a working cycle signature by a sensor system associated with a press.

Referring first to *Figures 1* to *4* of the drawings, there is shown a system incorporating apparatus for monitoring the operation thereof.

The system, in this embodiment an arrangement for manufacturing gear boxes, is divided into a plurality of manufacturing processes, for example three processes A, B and C as shown in *Figure 1*. Each of the processes A, B and C is concerned with the manufacture of a gear box for a particular make of car. There will therefore be general similarities between the processes A, B and C but, of course, details will differ from process to process depending upon the particular requirements for the gear box being manufactured.

The processes A, B and C define respective zones 1, 2 and 3 of the monitoring apparatus.

Each zone has a first processor means associated with the process carried out in that zone. Each first processor means comprises a zone microprocessor station C1, C2 or C3 which monitors the process A, B or C, respectively, being carried out in the zone. The outputs of the microprocessor stations C1, C2 and C3 are fed to a second microprocessor means in the form of a central computer 4 which is preferably a main frame computer such as an IBM 370.

The central computer 4 has a data base 5 containing information on the production capacity, demand, system and/or production flexibility, maintenance requirements, quality control, energy conservation requirements and any other data necessary for the efficient operation of the system. Thus, the central computer 4 is provided with sufficient information to allow decisions to be taken with regard to the options available in the event of a machine involved in one of the processes becoming unserviceable.

Referring now to *Figure 2*, each process, A, B and C, can be considered as a plurality of discrete steps or operations S1 to S7. Thus, in the case of the manufacture of the gear box, step S1 may be an absolute geometry examination of a gear box casting and alignment thereof for the second step S2 which may be a first stage numerically controlled machining operation. After step S2, the gear box casting passes to a step S3 for a geometrical tolerance inspection and then sequentially to steps S4, S5, S6 and S7, step S7 being a final inspection of the fully machined gearbox.

A respective sensor means comprising at least one transducer T1 to T7 is linked to each step S1 to S7 of each process A, B and C. Thus, an operational characteristic or signature of a machine involved with a particular step, or of an article being manufactured, is sensed or measured. Thus, the transducers T1 to T7 may measure for example, the dimensions of the gear box casting at step S1 and at step S2 may measure the distance moved by a part of a machine or sense a hydraulic pressure exerted by a machine during the numerically controlled machining operation. Of course, any partic-

ular features of the machine involved in the process or of the article being manufactured can be sensed or measured. Each signature or operational characteristic may also comprise a combination of

5 different measurements or features of the machines being used or the article being produced.

Each transducer T1 to T7 outputs a signal representing the operational characteristic or signature sensed to the associated zone microprocessor station C1 to C3. Each zone microprocessor station C1 to C3 comprises a microprocessor, which serves to compare each signal from the transducers T1 to T7 with a predetermined desired signature which is stored in a long term memory. If the microprocessor detects that there is a variation between one or more of the predetermined desired signatures and the associated detected signal, a warning is supplied to alert a zone - supervisor. Thus, either an audible or visual (or both) warning may be provided. The microprocessor at the zone microprocessor station C1, C2 or C3 also identifies the transducer T1 to T7 from which the abnormal operational characteristic or signature is being output and supplies this information to the zone supervisor by means of either a visual display unit (not shown) or a printer (not shown) located at the zone microprocessor station. Of course, the operation of comparing the signatures sensed by the transducers T1 to T7 with the predetermined desired signatures may be carried out using a specialised comparator or signature monitor recorder associated with each transducer and having stored in a long term memory thereof the predetermined desired signature which is obtained when the respective step S1 to S7 of the process A, B or C is first set up.

A respective diagnostics unit D1, D2 and D3 is associated with each zone microprocessor station C1, C2 and C3 and is connected thereto. Preferably, each diagnostics unit comprises a microcomputer and suitable software to enable the microcomputer to act as a diagnostics unit. As shown in Figure 4, each diagnostics trolley also comprises a visual display unit and a print unit (both of which may also act as the display for the zone microprocessor station) together with one or more signal process modules, one or more calibration modules and a chart recorder.

When a zone supervisor is alerted to the presence of an abnormality in a signature by the microprocessor station C1, C2 or C3, the associated diagnostics unit may be used to interrogate the sensed signatures being received at the microprocessor station against the stored predetermined desired signatures to ascertain the particular step in the process which is giving rise to the problem. Diagnostic programs for each step in the process may be stored in a mass store at the zone microprocessor station and, having ascertained the particular step which is giving rise to the problem, the diagnostic unit may search the store for the appropriate diagnostic program or programs and load them into a memory associated with the microcomputer of the diagnostic unit. Alternatively,

65 when the process is not a complex one, the diag-

nostic programs for each step may be held on the diagnostic unit by storage on cassette tapes or floppy discs. The diagnostic unit is then uncoupled from the zone microprocessor and taken to the particular step of the process which is giving rise to the problem where it is connected with the transducer or transducers for that step and the diagnostics program is used to diagnose the problem. A prognosis is then presented for example by display on the visual display unit and this may be passed by way of the zone microprocessor station to the central computer 4 for higher management decision if the problem cannot be rectified at the zone level.

As mentioned above, the central computer provides a data base of information comprising production outputs for each zone, forthcoming work loads for each zone, a history of machine flexibility, maintenance requirements for each zone, quality control requirements and energy conservation requirements so that, should a zone become unusable because of a faulty machine, the best course of action to maintain the desired production output can be decided. Thus, if, for example, zone 1 develops a fault in a sequence and the prognosis calls for a down time corrective maintenance operation, a critical path analysis program would determine whether zones 2 or 3 could meet extra capacity. Further, the watchdog capability of the system to allow pre-planned down time to minimise production losses by anticipating and taking remedial action to avoid a sudden, and possibly very costly, machine failure is of great benefit.

Apparatus in accordance with a second embodiment of the invention will now be described with reference to 10 Figures 5 to 8 of the drawings, the apparatus being incorporated in a system comprising three lines of presses.

As is shown in Figure 5, the system has three operational zones, Z1, Z2, Z3, each comprising a line of seven linked presses P1, to P7, inclusive. Each press line may produce the same pressing or a different pressing may be produced by each press line, the sequence of pressing operations commencing with a material blank at press P1 in each zone and ending with a final pressing operation at press P7 in that zone.

A respective sensor means associated with each press comprises strain gauge transducers S1 to S6 inclusive attached to appropriate component parts, generally the connecting rods, of each press, this being illustrated in Figure 7 with reference to the press P1 of any one of the zones Z1, Z2 or Z3. The art of strain gauging load carrying components in order to obtain appropriate output signals being known will not be described here. It is sufficient to say that during a working cycle of the press each strain gauge transducer outputs a signal representative of the load in the component to which it is attached and these signals are fed, by way of a junction box J1, to comparison means comprising a signature monitor recorder M1. The signature monitor recorder M1 comprises a microprocessor 31 a short term memory 32 and a long term memory 33.

The signals obtained from the transducers SI to S6 are referenced against time and stored as real time signatures in the short term memory 32. A reference signature obtained after first setting up and alignment of the press is stored in the long term memory 33.

Referring again to Figure 5, it will be seen that each press PI to P7, inclusive, has its own signature monitor recorder MI to M7, respectively, and that each signature monitor recorder in a zone is connected to first processor means comprising a microprocessor 34, a short term memory 35 and a long term memory 36 (reference Figure 7) at respective zone microprocessor stations CI for zone ZI, C2 for zone Z2 and C3 for zone Z3.

Connected to the first processor means at each respective zone microprocessor station CI, C2, C3, is a diagnostic unit DI, D2, D3, respectively. Each diagnostic unit DI, D2, D3, respectively, comprises a trolley mounted interface unit 37, microcomputer 38 and visual display unit/printer 39, these items being shown in Figure 6 with reference to the diagnostic unit DI of zone ZI. As is also shown in Figure 6 by broken lines the diagnostic unit DI may be disconnected from the zone microprocessor station CI and wheeled to the location of any one of the presses PI to P7, inclusive, where it may be connected with the signature monitor recorder of that press.

As shown in Figure 5 each of the zone microprocessor stations CI, C2 and C3, is connected to second processor means comprising a mainframe computer MFI.

In setting up the presses for operation of the system the diagnostic unit may be connected to the signature monitor recorder of a press and the signature monitor recorder may be switched by switching means (not shown) so that signals output by the transducers are fed direct to the microcomputer of the diagnostic unit. These signals referenced against time may be displayed on the visual display unit (VDU) of the diagnostic unit and processed to obtain information relative to correct setting of the die, blanking tool or other tool associated with the particular press being set. When the press is correctly set the signatures for an ideal operation of that press are obtained on the microcomputer and the signature monitor recorder is switched so that these signatures can be input to the long term memory of the signature monitor recorder for storage and subsequent comparison with signatures obtained during working load cycles of the press.

The reference signatures of all of the presses in an operational zone are stored in the long term memory of the first processor means at the zone microprocessor station.

When the presses of a line of presses have been set up and operation commenced, material blanks are fed to the first press in the line for a first drawing operation and the resulting pressing or piece part is then conveyed to the next press in the line for a subsequent operation such as hole blanking or cropping. After the final operation on the last press in the line a finished pressing or piece part is

obtained.

With particular reference to Figure 8, during the working cycles of each press in a press line working load signals are obtained from the transducers on each press and these signals referenced against time are fed as working load signatures to the short term memory of the signature monitor recorder. These working load signatures are then compared by the microprocessor of the signature monitor recorder with the reference signatures stored in the long term memory. When a difference of more than a predetermined amount is detected between the working load signatures and the reference signature an error signal is output by the signature monitor recorder to the first processor means at the zone microprocessor station where it is used to produce an audio and/or visual warning signal to alert a zone supervisor. The error signal may also be used to produce an audio and/or visual warning signal at the aberrating press.

On occurrence of an error warning signal at the zone microprocessor station the zone supervisor may use the diagnostic unit to interrogate the first processor means at which location he is able to compare the working load signatures of all of the presses in the zone against the reference load signatures for those presses which are stored in the long term memory of the first processor means. From this interrogation he can establish if the trouble at the aberrating press is being brought about by a problem at an earlier press in the press line rather than by the press which is giving rise to the warning signal.

Having established at the zone microprocessor station the particular press requiring further attention, the zone supervisor loads a memory associated with the microcomputer of the diagnostic unit with the diagnostic program or programs for the aberrating press, these programs being held in a mass store at the zone microprocessor station, and then uncouples the diagnostic unit and wheels it to the particular press concerned. After coupling the diagnostic unit to the signature monitor recorder at that press he is able to interrogate the sensor means either by way of the signature monitor recorder or by switching the signature monitor recorder so that signals from the transducers of the sensor means are fed direct to the microcomputer of the diagnostic unit.

If all that is required is some adjustment of the press in order to obtain an acceptable operation then when this adjustment has been carried out a new set of reference signatures for that press are obtained on the microcomputer. The reference signatures stored on the long term memory of the signature monitor recorder are dumped and the new reference signatures are stored. Similarly, at the first processor means the reference signatures for the press in question stored in the long term memory are replaced by the new reference signatures.

At the same time the relevant data is transmitted from the zone microprocessor station to the mainframe computer where factory management is able to assess critical paths for press maintenance and

alternative 14 sources of manufacture if these are necessary because of low stocks of the pressing concerned. This is of particular importance should it be necessary to shut down the press line for a considerable period so as to effect a major repair to a press or replacement of a worn die.

By periodic interrogation of the first processor means at the zone microprocessor station when error signals are not being given the zone supervisor is able to detect trends in the press line and this should enable him to undertake corrective adjustment or preventative maintenance in non-productive periods.

It will be appreciated, of course, that the embodiments of the invention as hereinbefore described with reference to and as shown in the accompanying drawings are by way of example only, modifications and variations being possible.

For example, in the embodiment of Figures 5 to 8, a diagnostic unit may be used to service a number of zones, particularly if the first processor means of the zone microprocessor stations are grouped together.

Furthermore, it will be appreciated that apparatus in accordance with the present invention may be used with systems other than production line systems. In particular, the apparatus can be used in maintenance procedures. Thus, the apparatus may be used to effect routine maintenance of a vehicle such as a car or a helicopter. In such a case, the "process" described above comprises a vehicle and each "step" of the process comprises a particular maintenance check to be carried out on that vehicle.

## CLAIMS

1. Apparatus for monitoring the operation of a system having a plurality of operational zones, each zone having a plurality of operational characteristics, the apparatus comprising: a respective sensor means for detecting each operational characteristic; a plurality of first processor means each associated with a respective operational zone for receiving signals representing the operational characteristics of the zone, for identifying when an operational characteristic of the zone varies from a predetermined desired characteristic and for delivering an error signal when a variation is detected to alert a zone supervisor; and a second processor means for receiving data from the plurality of first processor means to control overall operation of the system.

2. Apparatus according to Claim 1, wherein each operational characteristic is produced by a respective operational location in a zone and a plurality of diagnostic units are provided for determining the reason for a variation in an operational characteristic, each diagnostic unit being associated with a respective zone and first processor means and being movable between operational locations in the zone so that, when a first processor means delivers an error signal, a zone supervisor may move the associated diagnostic unit to the operational location at which the operational charac-

teristic variation is occurring to determine the reason for the variation.

3. Apparatus for monitoring the operation of a system having a plurality of operational zones, each zone having a plurality of operational locations each having an operational characteristic, the apparatus comprising: a respective sensor means for detecting each operational characteristic; a plurality of first processor means each associated with a respective operational zone for receiving signals representing the operational characteristics of the zone, for identifying when an operational characteristic of the zone varies from a predetermined desired characteristic and for delivering an error signal when a variation is detected to alert a zone supervisor; and a plurality of diagnostic units for determining the reason for a variation in the operational characteristic of an operational location, each diagnostic unit being associated with a respective zone and first processor means and being movable between operational locations in the zone so that when a first processor means outputs an error signal a zone supervisor may move the associated diagnostic unit to the operational location at which the operational characteristic variation is occurring to determine the reason for the variation.

4. Apparatus according to Claim 2 or 3, wherein each diagnostic unit comprises a trolley mounted interface unit, microcomputer and visual display unit.

5. Apparatus according to Claim 1, 2, 3, or 4, wherein comparison means are provided for comparing the operational characteristics sensed by the sensor means with predetermined desired operational characteristics and for delivering signals representing the variation between the operational characteristic sensed by each sensor means and the corresponding desired operational characteristic to the associated first processor means.

6. Apparatus according to Claim 5, wherein the comparison means comprise a respective comparator associated with each sensor means.

7. Apparatus according to Claim 5 or 6, wherein each comparison means comprises a signature monitor recorder including a microprocessor, a short term memory and a long term memory.

8. Apparatus according to any preceding claim, wherein each first processor means is provided with a display means for indicating variations in the operational characteristics of the associated zone.

9. Apparatus according to Claim 8, wherein the display means comprises a visual display unit.

10. Apparatus according to Claim 8 or 9, wherein the display means comprises a printer.

11. Apparatus for monitoring the operation of a system, having a plurality of operational zones, each zone having a plurality of operational characteristics substantially as hereinbefore described, with reference to, and as illustrated in Figures 1 to 4 of the accompanying drawings.

12. Apparatus for monitoring the operation of a system, having a plurality of operational zones each zone having a plurality of operational characteristics substantially as hereinbefore described,

with reference to, and as illustrated in Figures 5 to 8 of the accompanying drawings.

13. A system having a plurality of operational zones, each zone having a plurality of operational characteristics, the system incorporating apparatus in accordance with any preceding claim.

14. A product whenever produced using a system in accordance with Claim 13.

15. Any novel feature or combination of features described herein.

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